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13. ABSTRACT *(Maximum 200 Words)*
The objective of this study was to determine energy expenditure in servicewomen in various military settings and to determine if differences in total daily energy expenditure (TDEE) are explained primarily by differences in body size and fat-free mass after differences in activity patterns are accounted for. As originally planned, 5 field studies were conducted. A total of 80 Females (FFM = 45.9 ± 7.1 kg) were studied with an average of total daily energy expenditure of 3340 ± 1270 kcal/d. A total of 53 males (66.3 ± 9.0 kg FFM) were studied, with an average TDEE of 4870 ± 1480 kcal/d. Since men were larger than women in all studies, men had a higher TDEE than women overall, and in each individual study. However, when adjusting for differences in body size, the energy expenditure of men and women were similar in all studies. Energy expenditures during the short term Crucible studies were very high, possibly some of the highest energy expenditures we observed, and higher than the other 3 studies. The Crucible studies provided an excellent paradigm to examine energy expenditures between men and women because all recruits underwent essentially the same activities and were on the same sleep/wake regimen.

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4. INTRODUCTION

Women comprise 12.3% of the U.S. military active duty personnel, or approximately 200,000 servicewomen (as of June 30, 1993) (1). This is a significant number even compared to the 1,518,752 active duty men in military service, yet nutritional requirements of women have been far less studied than for men.

Energy Requirements in Women

Although energy requirements of male soldiers have been and continue to be assessed by our labs (USARIEM and PBRC) and others under several environmental and training conditions using the doubly labeled water (DLW) method, energy requirements of female military personnel have not been studied.

Several studies which have included a subset of female subjects, have examined nutrient intake, which may give some idea of energy requirements. A recent assessment of intake was made in 49 Army women by a visual estimation method during an 8-week cycle of the Army Basic Combat Training course (2). Reported intake was 2592±500 kcal/d, which was within the range of energy intakes of 2000 - 2800 kcal/d for female soldiers ages 17-50 years old as defined by the Military Recommended Dietary Allowances MRDA (3). However, the range of intakes ranged from a low of 1294 to a high of 4388 kcal/d. Some of this is certainly due to errors in estimating energy intake, while some is due to true variations in intake. Energy deficit based on body composition changes averaged 180 kcal/d suggesting energy expenditures as high as 2800 kcal/d (4). Consumption of several micronutrients were less than adequate. Vitamin B_6 (76%), Folic acid (65%), calcium (73%), zinc (73%) and iron (90%) were each consumed at levels lower than that of the MRDA. These inadequate intakes point to a potential problem women may encounter when consuming military field rations. The nutrient density of these rations was designed with the higher energy requirements of males. A female recruit consuming meal ready to eat (MRE)s at an expenditure level of 2400 kcal/d would need to consume 131% of energy requirements to meet her daily needs for calcium and as high as 166% of energy requirements to meet her daily needs of iron. It may be necessary to supplement the rations with specific micronutrients to be used by those with lower energy intake requirements or design specific rations for smaller women soldiers.

The objective of the current study is to define a range of energy requirements of servicewomen, defining the variation (with adjustments made for body size/composition) as it relates to jobs, military settings, and activity patterns. This is crucial information needed not only for determination of nutritional requirements for energy balance, but specific nutrient density standards for servicewomen. This will address the first and third specific nutrition topics of the IOM report. Total daily energy expenditure will be measured using the doubly labeled water (DLW) method. As part of the DLW method, total water turnover can be calculated from deuterium elimination and total body water. Corrections are made for atmospheric water exchange, metabolic water and isotopic fractionation. From these calculations we can estimate actual fluid consumption in the field (the second nutrition topic) and fluid requirements during specific categories of jobs and tasks (third nutrition topic). Activity patterns from actigraphs will be analyzed for hours of sleep, description of job/work patterns by examining bursts of concerted activity versus steady activity. Activity patterns will also be assessed using a boot insert which

measures locomotory activity and voluntary energy expenditure. Men will also be studied in many of these settings. Energy requirements for men have been better established and will serve to anchor the results obtained in women to previously established norms in men (or confirm the validity of significant deviations also observed in the female data). We hypothesize that in some settings, there may be smaller differences between genders (normalized for fat free mass (FFM)) than in Army basic training, if absolute rather than relative, or ability group standards are emphasized. Such a finding would help demonstrate and explain a wider possible variation in female energy requirements.

5. BODY

TECHNICAL OBJECTIVES

KEY OBJECTIVES

I. Define energy expenditure in servicewomen in various military settings.
II. Determine if differences in total daily energy expenditure (TDEE) are explained primarily by differences in body size and fat-free mass after differences in activity patterns (locomotory and by wrist-worn actigraphy) are accounted for.
III. Determine if the same holds true for differences between typical men, small men, and women.
IV. Test methods which may be useful in prediction of TDEE.
V. Assess hydration status of men and women by deuterium turnover (part of DLW).
VI. Compare TDEE assessed by footstrike monitor to DLW.
    A. Laboratory study: Demonstrate that the foot contact monitor (FCM) method provides valid estimates of the loco in military-eligible women over a full range of walking and running speeds, regardless of the phase of the menstrual cycle.
    B. Field study: Establish the validity of estimates of total daily energy expenditure (estimated TDEE), calculated from FCM determinations of loco and resting metabolic rate, in female soldiers engaged in military training at the Marine Corps Mountain Warfare Training Center (MCMWTC), Bridgeport, California. The doubly labeled water measurements of TDEE will serve as a reference standard (measured TDEE).

We hypothesize that estimates of total daily energy expenditure of women soldiers in the field (estimated TDEE) will provide valid estimates of actual TDEE (measured TDEE). Valid estimates of TDEE by the Foot Contact Monitor/Resting Metabolic Rate method would suggest that minute-to-minute loco data can be used to estimate macronutrient requirements associated with military training in mountainous terrain. This type of information is urgently needed to improve the match between macronutrient demand and macronutrient availability from rations and body energy stores.

STATEMENT OF WORK

Technical Objective: Determination Of Total Daily Energy Requirements, Water Turnover, and Activity Patterns of Servicewomen in Various Military Settings and Jobs

I. Months 1-2: Preparation Phase
   A. Protocol Development
   B. Contact and clearly define FTXs
   C. Hire/Train Personnel
   D. Order DLW dose for first year
   E. Order Actigraphs and components for Foot Contact Monitor
   F. Principal Investigators Meet to discuss and refine protocols

II. Months 6-18: Army Basic Training Field Study
   A. Coordination Trip
   B. Recruitment Trip
   C. DLW dose preparation and shipment
   D. Study team arrive and set up for field study
   E. Conduct Energy Expenditure and Activity Pattern Study
   F. Study team ship back equipment and samples
   G. Isotope Analyses
   H. Report Preparation

III. Months 11-23: Marine Basic Training Field Study
   A. Coordination Trip
   B. Recruitment Trip
   C. DLW dose preparation and shipment
   D. Study team arrive and set up for field study
   E. Conduct Energy Expenditure and Activity Pattern Study
   F. Study team ship back equipment and samples
   G. Isotope Analyses
   H. Report Preparation

IV. Months 16-28: Mountain Warfare Training Field Study
   A. Coordination Trip
   B. Recruitment Trip
   C. DLW dose preparation and shipment
   D. Study team arrive and set up for field study
   E. Conduct Energy Expenditure and Activity Pattern Study
   F. Study team ship back equipment and samples
   G. Isotope Analyses
   H. Report Preparation

V. Months 20-32: Shipboard Field Study
   A. Coordination Trip
   B. Recruitment Trip
   C. DLW dose preparation and shipment

D. Study team arrive and set up for field study
E. Conduct Energy Expenditure and Activity Pattern Study
F. Study team ship back equipment and samples
G. Isotope Analyses
H. Report Preparation

VI. Months 25-36: Army Units Field Study
A. Coordination Trip
B. Recruitment Trip
C. DLW dose preparation and shipment
D. Study team arrive and set up for field study
E. Conduct Energy Expenditure and Activity Pattern Study
F. Study team ship back equipment and samples
G. Isotope Analyses
H. Report Preparation

VII. Months 34-36
Prepare Final Report

SUMMARY OF PROGRESS

I. Months 1-2: First field training study identified, protocol developed, Personnel hired and trained, DLW dose water ordered, actigraphs ordered. We delayed purchasing new foot contact monitors as a new, improved version was being developed that is attached to the boot externally, so that we no longer have to have a custom boot insert made for the monitor. Therefore, for the first field training study, we used some of the old version that Reed Hoyt had on hand. We also delayed the validation study of the FCMs until the new version was received.

II. Months 6-18: The first field study was conducted at Fort Bragg/Camp Mckall, NC, in a Combat Support Hospital field study. Isotope analyses and energy expenditure calculations have been completed. Actigraph data were collected and analyzed.

III. Months 11-23: We were very fortunate that the opportunity arose to conduct energy expenditure studies in Marine Recruits undergoing the grueling Crucible event conducted at Parris Island, South Carolina. The USARIEM group was asked to conduct cold weather studies in January and February, and I was able to join the team as this project fit perfectly with the aims of this grant.

IV. Months 16-28:
A. We began the process of working out the details of our shipboard activities. We worked with W. Keith Prusaczyk, M.S., Ph.D., a Research Physiologist at the Naval Health Research Center in San Diego, California. A meeting occurred in San Diego, with Cathleen Kujawa, Jim Hodgdon, Dr. DeLany from PBRC and Dr. Beverly Patton from USARIEM where initial details were be worked out.
B. There were discussions about the possibility to conduct studies during basic training at the Great Lakes Training facility and in the Marines at Parris Island.
C. The new FCMs, which have been further revised to be attached to the boot laces, instead of on the side of the boot will arrive. We should receive some of these

new devices shortly. The laboratory validation study will be conducted and they will be available for future studies.

V. Months 25-48

A. Shipboard Study

1. The protocol for the Shipboard study was completed.
2. All necessary approvals were obtained.
3. A ship was identified, the Bonhomme Richard
4. Two potential dates were identified, one in November, 1999, and one in December 1999.

B. Marine Basic Training

1. Further discussions were conducted regarding a Marine Basic Training study at Parris Island.
2. We planned to study overweight and non-overweight women and men undergoing basic training.
3. This study was originally scheduled to occur during the Summer of 2000. However, due to logistical problems, this study has been rescheduled for the Spring of 2001.

C. Planning for an extra Final Field Study at Fort Jackson was conducted.

D. Due to logistical problems that often occur with Military Nutrition research studies, a one year extension was requested, and granted, through 25 October 2001 (See Appendix).

VI. Months 48-60

A. Our plans to conduct the Shipboard study aboard the Bonhomme Richard fell through and we were fortunate to identify another ship, and conducted the study in February, 2000.

B. The Marine Basic Training study was carried out.

C. We attempted to carry out an additional 6th Field Study at Fort Jackson but were unable to carry this study out due to lack of time.

D. Prepare Final Report

A. FIRST FIELD TRAINING STUDY

This study was a combined effort of the Military Nutrition and Biochemistry Division, the Sustainability Directorate and the Science and Technology Directorate of the Natick Research, Development, & Engineering Center (NRDEC), and the Pennington Biomedical Research Center to assess the nutritional adequacy for women of the Meal, Ready-to-Eat ration during a field training exercise. The study occurred during the field training exercise of a combat service support unit and investigated gender differences in food selection, nutrient intake, and energy expenditure.

TEST VOLUNTEERS

Volunteers were recruited from the 28 Combat Support Hospital (CSH), Fort Bragg, that were engaging in a field training exercise of approximately 14-days duration starting on 1 May 1997. The CSH anticipated deploying almost half of its 520 personnel. This unit strength included 150 women, but did not include approximately 50 FORSCOM nurses that train with the

unit. All soldiers from the unit who agreed to participate, except women who were pregnant, were included in the study.

Prior to the start of the study, the subjects were briefed on the nature and purpose of the study and the requirements for participation in the study and were familiarized with the experimental procedures. Subjects were informed verbally and in writing of their rights to withdraw from any part of the study without penalty or prejudice. The Commanding Officer of the prospective volunteers was informed of their responsibilities under AR 70-25 to ensure that the consent of any person under their authority to participate in this research is voluntary. Each subject completed a Volunteer Agreement Affidavit and Volunteer Subject Registry Data Sheet.

All volunteers were asked to participate in all data collection efforts. The volunteers were asked to complete questionnaires providing demographic information, medical history, diet history, nutrition knowledge and attitudes, to record all foods and fluids consumed for a total of seven days, and to record MRE lunches for an additional seven days. Individuals were asked to provide one blood sample and have body height taken once and body weights measured three times. A subsample of 32 volunteers were asked to participate in energy expenditure measures by a stable isotope technique and to wear wristband activity monitors and shoe liner foot contact monitors.

STUDY CONDITIONS

The experimental test period occured during a routine field training exercise in a temperate environment. The soldiers were provided three MREs per day for seven consecutive days during the field exercise. They were requested to eat no food other than that provided by the study team; however, the investigators were not take any enforcement measures. The importance of this restriction was explained to the CSH personnel at the orientation briefing. Bulk beverages or hot water typically available to combat service support personnel in the field were allowed.

A qualified medical monitor was supplied by the unit and was available during the entire experimental period. The medical monitor was responsible for terminating a volunteer's participation if medically indicated. Appropriate emergency medical service was available at Fort Bragg at all times during all tests.

STUDY DESIGN

The data collection schedule is shown below. An orientation briefing was provided at the beginning of the study. Baseline assessments were conducted at this time. Baseline/descriptive measurements include: height, weight, body composition by skinfold measures, and blood chemistries. Demographics and nutrition knowledge questionnaires and the Diet Habit Survey were administered on the day of baseline measurements.

This collaborative study of women soldiers provided a unique opportunity to study their physiologic responses a multi-stress military training environment. The broad objectives were to: (1) quantitatively determine energy expenditure, and (2) use ambulatory monitoring

technologies to make minute-to-minute measurements of soldier activity patterns and the metabolic cost of locomotion.

A. Test volunteers

30 volunteers, 2/3 female and 1/3 males, received doubly labeled water (DLW). The remaining 2 volunteers served as placebo controls. These subjects collected urine samples (salvia samples not necessary) at the same time as those drinking the DLW dose. This allowed for a correction factor to be calculated for any changes in isotopic baseline that might occur. Subjects were selected to obtain a variety of job classifications (MOS).

B. Experimental design

This study had a repeated measures design in which each test volunteer serves as his own control. The experimental design is outlined in Fig. 1 below.

Figure 1. Schedule of measurements.

	Days																
	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MRE (+/- A-rations)			-	-	-	-	-	-	-	+	+	+	+	+	+	+	
Field training exercise	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
DLW/$^2H_2{}^{18}O$ dose	x																
Saliva samples	x																
Urine samples	x	x	x						x	x	x		x		x	x	x
Food intake				x	x	x	x	x	x	x	x	x	x	x	x	x	
Body composition	x																x
Portable monitors*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

Note: DLW/$^2H_2{}^{18}O$ dose = doubly labeled water, stable isotope labeled hydrogen and oxygen.
*Portable monitors record activity and metabolic cost of locomotion.

PROGRESS

1) Doubly Labeled Water

All urine and saliva samples for the 30 dosed subjects and the 2 placebo subjects have been cleaned and prepared for isotope analyses. Deuterium and ^{18}O analyses are complete. Final calculations of total body water (for EE calculations and for estimation of fat free mass), and total daily energy expenditures have been calculated. Subject characteristics and energy expenditure data are presented in the following table. As expected, the men were heavier, had a higher fat free mass (FFM) and had a higher energy expenditure. This was true over the whole period, as well as before the field training exercise (PreFTX) as well as during the FTX at Camp Mckall. As a first adjustment for the differences in body weight, energy expenditures were simply divided by body weight. When this was done, and this is not necessarily the most appropriate method of adjustment, but it is often done, there are no differences in energy expenditure between the men and women. As expected, energy expenditures during the FTX were higher than that observed pre-FTX.

In addition to including women and men, subjects were selected to obtain a variety of job categories. Our original intent was to have similar breakdowns by job classification. However, we could not locate all of the subjects whom we had selected to obtain equal distributions (of those who had volunteered to participate in the study). We selected subjects from four major MOS groupings: (A) administrative; (M) medical which includes operating room specialists, practical nurses; (M1) Medical Specialists and Medical Lab Specialists; and (S) Utility Equipment Repair, Radio Operator, Medical Equipment Repair, Power Gen. Equipment Repair and Laundry Specialists. The numbers of each by gender, and the energy expenditures are given in the following table (Table 2). Energy expenditure was higher in men than women for each group. In addition, during the FTX, the lowest energy expenditures were observed in the administrative group.

Table 1. Subject characteristics and energy expenditure.

	Female	**Male**
	MEAN ± SE	MEAN ± SE
Age, y	27.2 ± 1.5	28.4 ± 2.5
Body Weight , kg	62.2 ± 2.5	88.2 ±3.8
FFM, kg	45.7 ±1.5	70.5 ±2.2
Energy Expenditure, kcal/d		
PreFTX	2192 ±123	3246 ± 180
FTX	2745 ±122	3959 ± 159
Entire period	2677 ±114	3881 ± 165
Energy expenditure, kcal/d divided by body weight		
PreFTX	37.8 ± 2.1	35.6 ± 1.4
FTX	44.9 ± 1.6	45.5 ± 2.2
Entire period	43.6 ± 1.4	44.4 ± 2.0

Table 2. Pre-field training exercise (FTX) and FTX energy expenditures (kcal/d) by gender and job category groupings.

Group	Male		Female	
	N	Mean ± STD	N	Mean ± STD
PreFTX				
A	1	3300	5	2220 ± 448
M	6	3150 ± 946	7	2372 ± 426
M1	1	3870	4	2614 ± 473
S	1	2729	3	1848 ± 248
FTX				
A	1	3709	4	2332 ± 373
M	6	3880 ± 872	6	2872 ± 229
M1	1	4261	4	2940 ± 268
S	2	4174 ± 431	3	2781 ± 320

A more thorough effort was undertaken to adjust energy expenditures for differences in body weight between the men and women. A more appropriate method than simply dividing energy expenditure by body weight is to use body weight or fat free mass as covariance analysis of variance to adjust for differences in body size. In addition to body weight or fat free mass, we included job classification group, since these were not entirely balanced between the males and females. These adjustments to energy expenditure are given below in Table 3. The adjustments for body weight are somewhat suspect, because most soldiers were in BDUs (Battle Dress Uniform) during the initial weight and we had to adjust the body weights. Therefore, adjustments using FFM (measured from isotope dilution as part of the DLW method) are more likely to be accurate. In addition, although the energy data have been broken down into the short pre-FTX (3 days) and the FTX, the data from the entire period, using linear regression to calculate elimination rates will be the more accurate measure of energy expenditure. Energy expenditure, adjusted for differences in body size and imbalances in MOS group, tended to be higher during the FTX in men compared to women. During the entire period, energy expenditure was significantly higher when adjusting for body weight (which was somewhat suspect) but not when adjusting for fat free mass.

Table 3. Energy expenditures adjusted for differences in body size using covariance analysis or variance.

Adjustments	Female	Male
FTX		
Body Weight	2983 ± 120	3507 ± 186
Body Weight + Group	2987 ± 114	3500 ± 175*
FFM	3058 ± 160	3364 ± 266
FFM + Group	3072 ± 151	3337 ± 251
Pre-FTX		
Body Weight	2393 ± 116	2819 ± 191
Body Weight + Group	2396 ± 118	2812 ± 195
FFM	2531 ± 140	2526 ± 254
FFM + Group	2547 ± 143	2492 ± 260
Entire period, by linear regression		
Body Weight	2907 ± 106	3398 ± 176*
Body Weight + Group	2912 ± 101	3385 ± 168*
FFM	3031 ± 132	3135 ± 240
FFM + Group	3046 ± 124	3102 ± 226

Another way to examine energy expenditure is to plot the individual energy expenditure data points versus fat free mass or body weight. When this is done, the male and female soldiers fall along the same regression line.

2) Activity monitor data

There were no significant differences in Actigraph activity data between males and females. Time spent awake and during sleep, as well as activity events were nearly identical between men and women. The mean daily counts tended to be slightly higher in women (141 vs 131), while the activity events greater than 4 minutes and mean counts during activity tended to be higher in men (5.4 vs 4.6 and 182 vs 130, respectively).

Table 4. Actigraph activity data.

	Females	Males	p
Mean Counts	141 ± 3.3	131 ± 5.5	0.14
Wake, minutes	854 ± 18	850 ± 30	0.90
Sleep, minutes	445 ± 17	489 ± 28	0.19
Sleep latency	26.3 ± 5.5	34.6 ± 94	0.45
Activity events	10.2 ± 0.8	10.2 ± 1.4	0.98
Mean Counts, during activity events	130 ± 21	182 ± 36	0.22
Activity events > 5 minutes	4.6 ± 0.3	5.4 ± 0.5	0.16

Data from the activity monitors was used to develop models to approximate energy expenditure measured by DLW. The first model used calculated RMR (based on FFM, (12) multiplied by waking minutes and the mean activity counts (divided by 100, which approximates a multiple of RMR) plus calculated RMR times sleeping minutes, with the sum divided by 1440 minutes/d. In addition, a further activity factor was added using the activity events multiplied by the mean activity counts during activity events, multiplied by weight, and finally divided by 100. The second model was much simpler, estimating activity by multiplying body weight by activity events and the mean activity counts during activity events, divided by 100, then adding RMR. The model fit (r2 and p) and energy expenditure for females and males is given below. Although the mean values are very close to the DLW values for energy expenditure, the models explain only 55 and 65 % of the variance. Therefore, further work is needed before Actigraph data can be used to estimate energy utilization.

Model 1

$$\frac{(RMR\ x\ Wake\ x\ mean/100 + RMR\ x\ Sleep)}{1440} + Activity\ Events\ x\ mean\ during\ activity\ x\ weight/100$$

Model 2

$$Activity\ Events\ x\ Mean\ Activity\ Counts\ During\ activity\ x\ weight/100 + RMR$$

	r^2	p	Females	males
Model 1	0.55	0.0001	2890 ± 134	4012 ± 227
Model 2	0.65	0.0001	2610 ± 100	3674 ± 169
DLW			2678 ± 117	3864 ± 192

B. MARINE RECRUIT CRUCIBLE STUDIES (TWO STUDIES)

We were very fortunate that the opportunity arose to conduct energy expenditure studies in Marine Recruits undergoing the grueling 54.4-hour Crucible event conducted at Parris Island, South Carolina. This gave us the opportunity to study very high energy expenditures in men and women undergoing the same intense training program. The USARIEM group was asked to conduct cold weather studies in January and February, and I was able to join the team as this project fit perfectly with the aims of this grant. Those individuals who were involved in collecting the data in the field included: James DeLany - PBRC; John Castellani, James Moulton, Kate OBrien, Bill Santee - USARIEM. Since the lead time on the January study was very short, we were not able to use any of the activity monitoring devices. However, we were able to use both the actigraphs, and the new foot contact monitors during the second iteration of the Crucible Studies. Volunteer recruitment was conducted as described under the first field study. The general and detailed study protocols are given below.

STUDY DESIGN/CONDUCT

1. Energy expenditure studies in a subset during two Crucible Studies
   a) 15 men
   b) 10 women

2. Jan-98 Study
   a) Doubly labeled water
   b) Weather data
   c) Intake measurements

3. Feb-98 Study
   a) DLW
   b) Actigraph data
   c) Foot contact monitor data
   d) Weather data
   e) Intake measurements

- Protocol

  »Baseline Urine Wednesday afternoon

  »DLW dose Wednesday afternoon

  »0200 Thursday Urine

  »2300 Thursday / 0400 Friday Urine

  »2300 Friday Urine

  »0800 Saturday Urine

In addition, a considerable amount of weather information was gathered throughout the studies. Dietary intake was estimated by having the participants save all Meals Ready to Eat (MRE) wrappers in plastic bags, as well as writing any other food eaten, such as the fresh fruits

and hot wets that were also provided. The empty wrappers and other foods written down were then used to estimate food intake throughout the study. This process was made somewhat easier because the soldiers only received two MREs throughout the study.

PROGRESS

Isotope analyses have been completed are calculations completed. The calculations for this study were more complicated than those for the first field study because the participants in this study were underfed considerably, and therefore used substantial body stores to make up the caloric deficit. This is important, because in the calculation of energy expenditure from the calculated CO_2 production, one uses a caloric equivalent of CO_2 based on the substrates utilized during the study. Normally, during weight maintenance, that would be equivalent to the dietary intake. However, when substantial body stores are also used for energy, this must be taken into account. The calculations for the food quotient (FQ) used for the DLW calculations are given below. The body weight loss data is given in the Appendix.

Parris Island - FQ Calculations - Men

Assume 300g glycogen, 80% fat

Hours	kcal/d	EE total	Intake	Deficit	Fat	Protein	Carb.
54.4	6300	14283	3239	11044	7875	1969	1200
					875	492	300

	Substrate (g)					kcal	total	per g substrate	
								CO2	O2
	diet	body	total	CO2	O2	/L CO2	kcal	formed	used
Prot	101	492.2	593	459	573	5.579	2561	0.774	0.966
CHO	448	300.0	748	620	620	5.047	3130	0.829	0.829
Fat	123	875.0	998	1424	2015	6.629	9441	1.427	2.019
				2503	3208		15132		
			RQ	**0.780**		**kcal/L CO2**	**6.045**		

Parris Island - FQ Calculations - Women

Assume 240g glycogen, 80% fat

hours	kcal/d	EE total	Intake	Deficit	Fat	Protein	Carbohydrate
54.4	4770	10814	2580	8234	5819	1455	960
					647	364	240

	Substrate (g)					kcal	total	per g substrate	
								CO2	O2
	diet	body	total	CO2	O2	/L CO2	kcal	formed	used
Prot	98	363.7	462	357	446	5.579	1994	0.774	0.966
CHO	400	240.0	640	531	531	5.047	2678	0.829	0.829
Fat	116	646.6	763	1088	1540	6.629	7214	1.427	2.019
				1976	2516		11885		
			RQ	**0.785**		**kcal/L CO2**	**6.014**		

The energy expenditures for each of the Crucible studies is given in the following table. The detailed data is presented in the Appendix 3 and 4. As in the previous field study presented above, energy expenditure was significantly higher in men than women. With the results of the two Crucible studies combined (Table below) one can see that the men were considerably heavier than the women, and had a significantly higher energy expenditure. However, when dividing by body weight energy expenditures were similar. In addition, when plotting energy expenditure vs. body weight, although there is a great amount of variation around the line, there does not appear to be any difference between men and women. Of interest, and as expected, energy expenditures were much higher in the Crucible studies compared to the combat support hospital study. Energy expenditure in women was nearly 2000 kcal per day higher in this study, and nearly 1000 kcal/d higher than the men in the previous study.

Total Daily Energy Expenditure During Each Crucible Study

	EE, kcal/d		EE, kcal/kg/d	
	Mean	**SD**	**Mean**	**SD**
JANUARY CRUCIBLE				
Men	6448	868	91.1	15
Women	4800	576	83.5	15
FEBRUARY CRUCIBLE				
Men	5787	1085	80.8	18
Women	4653	725	80.8	18

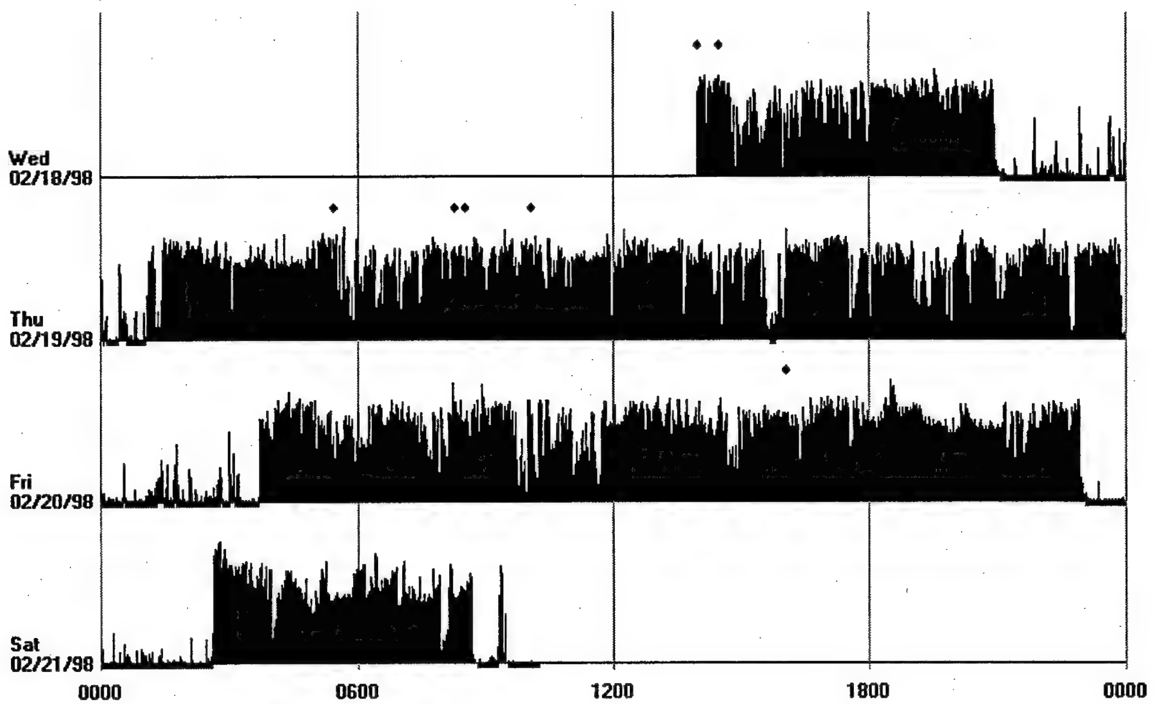
Crucible Energy Expenditure Data – Both Studies Combined

	Female	**Male**	**p**
Weight, kg	57.8 ± 1.8	72.2 ± 1.5	0.0001
Energy Expenditure, kcal/d	4230 ± 190	6080 ± 160	0.0001
EE/wt (kcal/kg)	83.4 ± 3.7	85.2 ± 3.0	0.72

Analysis of the Actigraph data has been completed and is presented in the following table. The figure below depicts a typical output for the Crucible studies, indicating the little time for sleep in these studies. The mean counts in the Crucible study was considerably higher than that observed in the Combat Support Hospital study, as expected. As in the previous study, there were no differences in counts, activity events, mean counts during activity events, sleep or wake minutes between men and women.

Actigraph Data (per 24 hrs) - Parris Island 2

	Female	Male	p
Mean counts	216 ± 3	212 ± 2	0.26
Mean counts during activity events	348 ± 18	349 ±16	0.98
Wake, minutes	960 ± 5	968 ± 4	0.25
Sleep, min	133 ± 5	126 ± 4	0.25
Counts during activity	348 ± 18	349 ± 16	0.98



C. VALIDATION OF FOOT CONTACT MONITORS

METHODS

VOLUNTEERS

Eight (8) healthy volunteers were recruited from the U.S. Army Soldier Biological and Chemical Command (SBCCOM) Headquarters Test Volunteer Detachment and USARIEM.

PRE-TESTING

Prior to travel to the field test site, volunteers performed a continuous treadmill maximal oxygen uptake (VO_2max) test. Height, weight and age were recorded for each subject.

FIELD TEST PLAN

Preliminary data was collected at USARIEM before traveling to the field site. All field testing was done at YTC in eastern Washington. The plan was scheduled for mid-spring, after the winter thaw, while air temperatures were expected to be moderate. To ensure that subjects were not exposed to a significant potential for heat strain, no test session was started if the Wet Bulb Globe Temperature index (WBGT) exceeded 78°F.

The testing on different slopes (Table 1) was to occur in 9 sessions (4 mornings and 5 afternoons), over 5 days. Each volunteer was to attempt 3 load carriage tests or exercise bouts (1 each, while carrying no load, 13.6 kg [30 lbs] and 27.2 kg [60 lbs]) for the 7 test conditions. Those conditions were 3 uphill and 3 downhill slopes, plus the paved level condition. The grades tested were 0% (level), 4%, 8.6% and 12%. The volunteers carried the loads in a randomly assigned order during each session. Due to the logistics of setting up and moving test sites, testing could be conducted at only 1 slope or grade per day, starting with the level site. An option of repeating 1 test bout per subject per day was allowed to adjust for an equipment failure or other compromise of the test methods.

Each 20 min exercise bout was separated by at least a 40 min rest period. All exercise bouts were paced at 1.34 $m \cdot s^{-1}$ (3 mph). Initial testing began on the level site to enable subjects to become familiar with the test equipment. No more than 4 subjects participated during a given test bout.

Clothing for all exercise bouts consisted of the Battledress Uniform (BDU), combat boots and field cap. The loads were carried in an issue (ALICE) field pack that weighs 2.8 kg with a frame. Total weight of clothing, pack and oxygen monitor was approximately 8.8 kg. Each volunteer walked for 13-20 min at a time.

Data Collection

A Sensormedics 2900 (Yorba Linda, CA) metabolic measurement cart was used during the VO_2max test. During the outdoor exercise bouts, Oxylog portable oxygen consumption monitors (P.K. Morgan, Ltd., Gillingham, Kent, England) were used to collect data. Before exercising, each volunteer was fitted with a nose clip, and a mouthpiece attached to a hose directing expired gases to the Oxylog. Foot contact times were measured using a device based on accelerometers mounted on the foot. (Personal Electronic Devices, Wellesley MA). These devices recorded the foot contact time for every foot strike. Oxygen uptake was hand-recorded every minute during the exercise bouts. Subject weight, age and height were obtained at the time of VO_2max testing. Body weights, with underwear, were obtained on each test day prior to testing.

FIELD TEST SCHEDULE

The basic test plan was to record physiological values for subjects as they walked at a steady 1.34 m/s pace on varying slopes while carrying a pack with a load of zero, 13.6 kg or 27.2 kg. The test plan was that each subject would carry each load once per day in both up and downhill (3x2) directions for a maximum of 20 min. Each 13-20 min load carry was considered a test run/bout. We planned a maximum of 7 load carriage bouts (including 1 make-up) per

subject per day. On the level site, subjects were to carry each load once on the paved runway. Testing was conducted at only 1site per day. Subjects were to be tested in alternating groups of 4, so each subject had at least a 40 min break between test runs. A test matrix was designed so that presentation of loads was countered balanced, but no more than 2 subjects ever carried the same pack load during the same data collection run.

Each test run consisted of up to 4 subjects wearing the BDU uniform, combat boots and field cap carrying an LC-1 (ALICE) frame and pack with either no load (zero), 13.6 kg (30 lbs) or 27.2 kg (60 lbs) of lead shot in 1 l plastic bottles. Each individual was monitored with a sports watch style heart rate monitor, a telemetric temperature pill and a portable oxygen monitor. Data were hand-recorded every minute. The 1.34 m/s pace was set with a measuring wheel (Master Measure MM50, Rolatape® Corporation, Spokane, WA) modified with a bicycle cylometer (Enduro 2 CC-ED200, Cateye Company, Ltd, Boulder, CO). Weather conditions were measured with a Wet-Bulb Global Temperature (WBGT) monitor that displayed air, black globe and natural wet-bulb temperatures, plus a calculated WBGT value.

PROGRESS

SUBJECT POPULATION

Population variables (mean±sd) for the 8 male subjects were age (24± 4 yr), height (174 ± 7 cm) and weight (80.2± 9.9 kg). Maximum oxygen uptake (VO_2max) was 51.61 ± 4.62 mlO_2/min/kg. Percent body fat was 20.5 ± 4.7%. Table 2 lists individual values.

MISSING DATA

Missing data from Oxylog and Foot Strike detection equipment meant that only data from level walking with the 30 and 60 lb loads were considered for analysis.

METABOLIC COST OF LOCOMOTON

Estimates from VO_2

VO2 estimates were reported as mL O2 / Kg / min.
These estimates were converted to L O2 / min.
The value of 20.37 KJ / L was used to estimate the amount of energy burned by 1 Litre of O2.

Estimates from Foor Contact Time (Tc)

The equation from Hoyt et al was used to estimate energy expenditure from foot contact times:

$$\dot{M}_{Loco}(W)= m * (W_b/T_c) + c$$

Where m and c are modified from the original paper as the method of Tc measurment changed from Force Sensitive Resitors to Accelorometers.

m=3.935174825
c=-205.4265734

The table below shows the estimates of energy expenditure (Watts) for each estimation method and each load.

Subject	30 lb VO2	30 lb Tc	60 lb VO2	60 lb Tc
1	453.29	489.19	525.86	560.41
2	373.85	373.69	403.09	482.44
3	510.22	486.68	533.35	536.72
5	496.47	487.35	586.91	592.94
Mean	**458.46**	**459.23**	**512.30**	**543.13**
SD	**61.40**	**57.03**	**77.71**	**46.56**

ANALYSIS

The hypothesis is that the Tc method of estimating energy expenditure is valid. Using the VO2 method of estimation as a standard measure we compare the Tc method using a two factor (estimation method and loaded weight) repeated measures ANOVA.

Estimation Method	F=1.564	df (1,3)	P=0.300
Loaded Weight	F=29.945	df (1,3)	P=0.012
Interaction	F=2.958	df (1,3)	P=0.184

The above Table shows that as expected factor Loaded Weight is significantly different between the 30 lb load and 60 lb load where P=0.012. The factor estimation method (VO2 vs Tc) is not significantly different where P=0.300 and the interaction term is also not significantly different where P=0.184.

In order to examine the amount of variability explained by the Tc method of estimating energy expenditure two regression analysis were run between VO2 and Tc. The Figure below shows the results of the regression analysis. For 30 lbs the Tc method of estimation accounts for 83% where $R^2 = 0.8301$ of the variance and for 60 lbs the Tc method accounts for 92% where $R^2 = 0.9255$ of the variance.

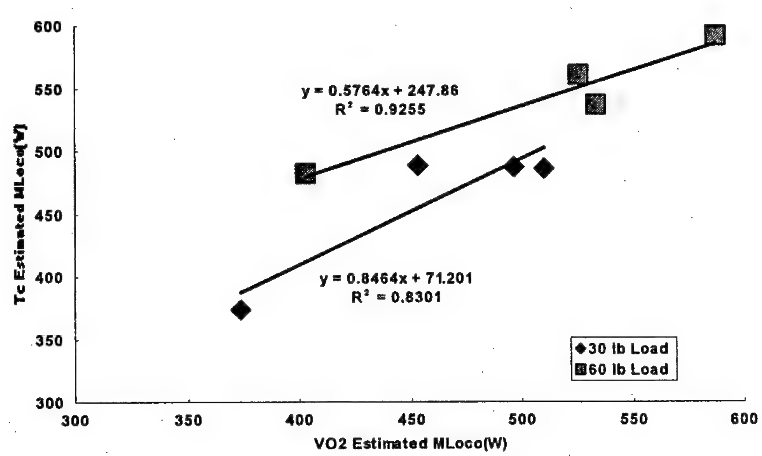


Figure: Regressions for VO2 and Tc estimates of MLoco with 30lb and 60lb load carriage weights.

D. ENERGY EXPENDITURE OF NAVY WOMEN ONBOARD SHIP

This study was a collaborative effort among NHRC, USARIEM, and the Pennington Biomedical Research Center. This collaborative effort allowed us to obtain more information than could have been achieved with the DWHRP grant alone. Kathleen I. Kujawa and James A. Hodgdon, Ph.D. from NHRC coordinated the shipboard activities and the body composition measurements. The dietary intake information, conducted by USARIEM was coordinated by MAJ Beverly D. Patton. The protocol was approved by the appropriate scientific and Human Use committees.

Beverly Patton, Jim Hodgdon, and Kathleen Kujawa met with the medical officers from the Bonhomme Richard and Amphibious Group 3. Both agreed to support the project. They next briefed their respective bosses (the ship's captain and the admiral in command of Amphib Group 3) and we were given the OK to move forward. Two possible study dates were identified, 08-19 November or 06-17 December Bonhomme Richard. We were going to try for the November date; that way, if anything fell through at the last moment, we still had another opportunity. We were able, however, to plan the study for the December dates, but it did fall through at the last minute. We were fortunate to identify another ship, the U.S.S. Essex, and conducted the study in February, 2000.

PROTOCOL OBJECTIVE

The objectives of this study were to:

1. To determine the average daily energy expenditure for women while performing various onboard occupational tasks.
2. To obtain information on the nutritional status, including body composition, of female personnel onboard ship.
3. To evaluate the shipboard activity patterns of female Naval personnel.
4. To determine if the nutritional recommendations as outlined in NAVMEDCOMINST 10110.1 are adequate to meet the nutritional needs of female Naval personnel onboard ship.

EXPERIMENTAL METHODS

- In-port: 8 days baseline data collection
- At-sea: 10 days

Subjects

- 20 Women
  - 9 serving in "high physical demands" ratings
  - 9 serving in "low physical demands" ratings
  - 2 Controls
- 11 Men
  - 5 serving in "high physical demands" ratings
  - 5 serving in "low physical demands" ratings
  - 1 Control

Subjects were 20 female and 11 male sailors serving aboard a ship homeported in San Diego, CA. Ten women and five men served in high physical demand ratings (Physical Demand Ratings (PDR) > 3.0) and ten women and five men served in low physical demand ratings (PDR < 2.0) (Vickers et al., 1997). It has been shown that PDRs give valid estimates of the physical demands of Navy enlisted ratings (Carter and Biersner, 1987). All subjects signed Informed Consent documents prior to their acceptance and participation in the study.

Dietary Intake

Dietary intake measurements were obtained both while subjects were in homeport (where subjects are free-living) and while the ship was underway (where dietary choice was more restricted). Subjects filled out a food frequency questionnaire while in port to assess usual intake. Aboard ship, food intake was measured using the visual estimation technique (Rose et al, 1991). This method is comparable in accuracy to the weighing method used for estimating individual dietary intakes (Schnakenberg et al, 1987). Trained recipe specialists collected information and data on recipe enhancements and recipe preparation in the ship's galley. The nutrient content of foods prepared in the galleys were calculated with a recipe analysis system developed by the Pennington Biomedical Research Center using military ration nutrient composition data from USARIEM's Military Nutrition & Biochemistry Division database.

Doubly Labeled Water

- Baseline urine and saliva samples collected
- Oral dose of 0.25 g/kg body weight $H_2{}^{18}O$ and 0.18 g/kg body weight ${}^2H_2O$
- Saliva sample at 2-4 hours post-dose
- Urine samples each morning

Activity Monitoring

Actigraphs (4 cm L x 3.1 cm W x 1 cm H, 57 g) were worn on the wrist of the non-preferred hand using a standard wristwatch band. The Actigraphs malfunctioned due to a software glitch because of a Y2K problem, so no data was obtained.

A foot contact monitor (Personal Electronic Devices, Wellesley MA, 5.8 cm X 7.6 cm X 6.4 cm; 57 g) was mounted to the outside of the boot.

PROGRESS

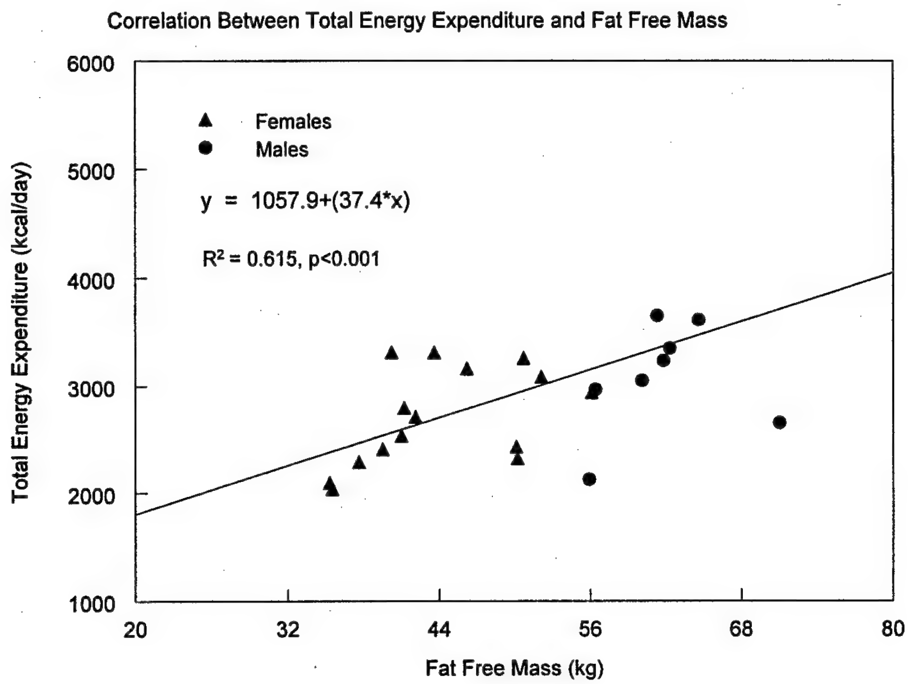
Energy Expenditure

Total body water (TBW) and fat free mass (FFM) were similar regardless of the isotope, ${}^2H_2O$ or $H_2{}^{18}O$, from which it was calculated. (Appendix 5) The females had significantly less TBW and FFM than the males.

Total energy expenditure (TEE) was calculated using a 2 point method and by linear regression of the sample points collected on day 0, 2, 7 and 8. There was no significant difference in TEE regardless of the method by which it was calculated (Appendix 5). The

females expended significantly fewer calories than their male counterparts. There was a significant correlation between FFM and total energy expenditure; the greater the FFM, the more total energy expended (Figure below).

Figure. Correlation between total energy expenditure and fat free mass.



The average daily energy expenditure of the female subjects was 2808 $\pm$ 429 kcal/day. This is significantly less than the energy expenditure of the male subjects 3473 $\pm$ 807 kcal/d. However, this difference in daily caloric energy expenditure was explained by a difference in body size. From the above graph, it is apparent that the men had a significantly greater fat free mass than the women, and that for all subjects, regardless of FFM (body size) TDEE is related to FFM.

Prediction of Shipboard Total Daily Energy Expenditures Using Pedometry

BACKGROUND AND RATIONALE FOR THE STUDY

Human energy requirements vary with activity level. The energy requirements for the vast number of military occupations are unknown and not necessarily the same for women as they are for their male counterparts. Previous research with men and women performing similar work has shown that energy requirements are not just a function of body mass differences. With greater percentages of women comprising the Armed Forces and more job specialties open to and attracting women, documenting unique nutritional requirements of women is important. The use of doubly labeled water to assess total daily energy expenditure in a free-living environment is widely accepted as highly accurate, but expensive. Pedometry based-technology offers the

potential for a considerably cheaper alternative to the doubly labeled water method to determine total daily energy expenditure, but whether these estimates with the less expensive technology are accurate is unclear.

PURPOSE

- To determine if pedometry measurements might provide an accurate and less expensive alternative to the doubly labeled water method for non-invasively assessing total daily energy expenditure in free-living military personnel.

RESEARCH APPROACH

- Used two different methodologies (doubly labeled water and pedometry) to compare and assess total daily energy expenditure in female and male sailors participating in a training mission at sea aboard a U.S. Navy Ship.

METHODS

U.S. Navy Sailors stationed aboard an amphibious assault ship resembling a small aircraft carrier served as test volunteers.

- Volunteers
  - 16 Women (age: 24.9 $\pm$ 1.1 yrs; ht: 163.8 $\pm$ 1.9 cm; wt: 67.8 $\pm$ 3.1 kg)
  - 9 Men (age: 23.8 $\pm$ 1.3 yrs; ht: 176.6 $\pm$ 3.1 cm; wt: 79.1 $\pm$ 4.4 kg)
- Measurements took place during an 8-day training exercise at sea
- Volunteers had jobs classified as physically active (e.g., working on the flight deck, maintenance, janitorial, food service: 10 women and 5 men) or as sedentary (e.g., supervisory, clerical, medical: 6 women and 4 men)
- Total Daily Energy Expenditure
  - Doubly labeled water ($H_2{}^{18}O$ + ${}^2H_2O$) technique from DeLany et al. (JAP: 67: 1922-1929, 1989)
  - Saliva samples to determine baseline isotope levels
  - Urine samples to determine changes in isotope levels
- Lean body mass obtained from ${}^2H_2O$ dilution space
- Pedometry (17 Volunteers; 10 women and 7 men)
  - Motion logger devices worn on shoelaces
  - Recorded activity in four modes (running, walking, slow foot movements, and no activity)

EQUATIONS USED

- Resting Metabolic Rate (RMR) determined as:
  RMR (kcal/day) = 500 + 22 (Lean Body Mass) from Cunningham, J.J. (AJCN: 33: 2372-2374, 1980)
- Predictive equation developed by modifying previous equation from Hoyt, R.W. et al. (JAP: 76: 1818-1822, 1994) with modifications resulting from study differences, namely:
  - Differences in type of foot monitor (force sensitive insole vs. motion

logger worn on the laces of the shoe)
• Differences in type of exercise (bouts of treadmill exercise vs. continuous movement in free-living environment)

STATISTICAL ANALYSES

- ANOVA to determine differences between genders, job classifications and pedometry vs. doubly labeled water assessments

- ANCOVA to determine if gender differences in total daily energy expenditure were due to body mass or fat free mass

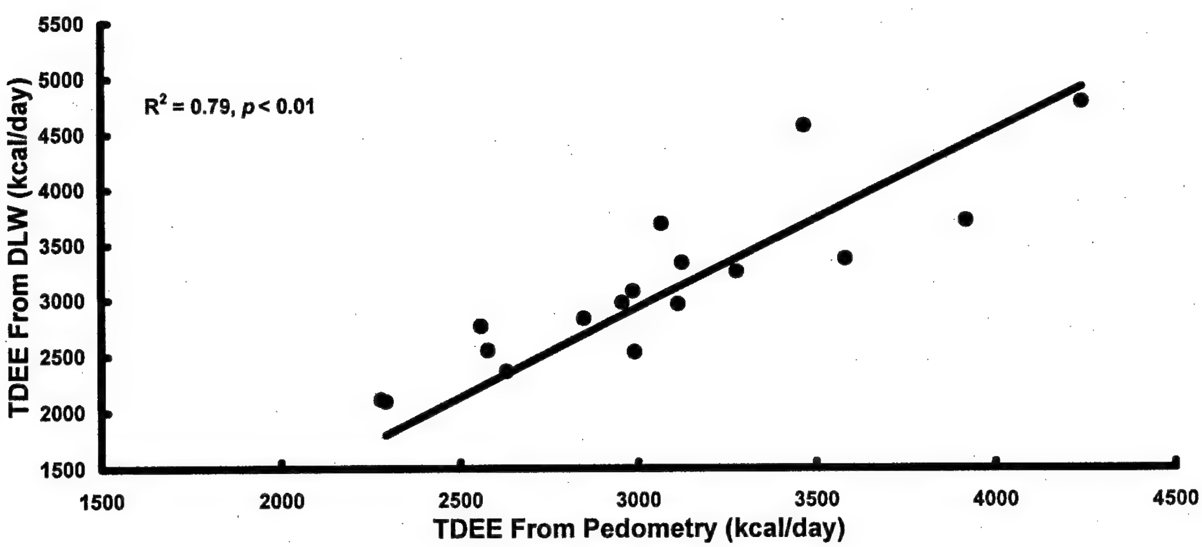
- Multiple regression analyses were used to determine the best prediction equation for total daily energy expenditure from pedometry measures and to compare the model's calculated total daily energy expenditure to that measured from doubly labeled water (the reference standard)

PROGRESS

- Prediction equation: TDEE = 1440 * [Percent of Time Spent Running *((0.0761) * [Body Mass / Contact Times During Running]) - 7.598) + Percent of Time Spent Walking * ((0.056) * [Body Mass / Contact Times During Walking]) - 2.938) + Percent of Time Spent Doing Other Foot Movements * (0.1 * Resting Metabolic Rate) + Resting Metabolic Rate]

The predicted TDEE from the

Total Daily Energy Expenditure (TDEE) From Doubly Labeled Water (DLW) vs. TDEE From Pedometry



Summary

An algorithm was developed for this study to estimate total daily energy expenditure using pedometry. Sailors (10 women, 7 men) were studied for 8 days at sea. The doubly labeled water

method was used to estimate total daily energy expenditure. Pedometry was used to measure (a) foot-ground contact time during running and walking, and (b) the fraction of time spent running, walking, or in other forms of foot movement such as shuffling and stair climbing. Resting metabolic rate was estimated from lean body mass. The new predictive algorithm is a variation of a previously developed model (JAP 76:1818-22, 1994), where Total Daily Energy Expenditure = 1440*[Percent Run Time*((0.0761*[Body Mass/Contact Time During Running])-7.598) + Percent Walk Time*((0.056*[Body Mass/Walk Contact Time])-2.938) + (Percent Other Foot Movement Time*0.1*Resting Metabolic Rate) + Resting Metabolic Rate]. This equation explained 79% of the variance relative to total daily energy expenditure obtained from the doubly labeled water technique. Total daily energy expenditure (Mean $\pm$ SEM: 3023 $\pm$ 99 kcal/day) predicted by pedometry (95% confidence = $\pm$193 kcal/day) did not differ from that predicted by doubly labeled water (3000 $\pm$153 kcal/day). The abundance of ramps and ladders on ships increased vertical locomotion components relative to horizontal, which normally predominate on land, possibly limiting the ability of pedometry to classify shipboard activity. However, total daily energy expenditure was predicted with reasonable accuracy using estimated resting metabolic rate and this pedometry method.

CONCLUSIONS

- Men had higher total daily energy expenditures than women but differences were fully accounted for by their greater body mass
- Job classification did not affect total daily energy expenditures
- Pedometers provided significant accuracy in assessing total daily energy expenditures
- Because the abundance of ramps and ladders on ships increased the vertical locomotion components relative to the horizontal, the predictive capabilities of pedometry may improve during land navigation scenarios
- Future research is necessary to validate this equation using these monitors in other locomotion scenarios
- Pedometry appears to be a possible alternative and more cost effective method than doubly labeled water when assessing energy expenditure

Inadequacy of Diets of Female Sailors at Sea.

The adequacy of shipboard diets of Navy women relative to the energy demands of their jobs was examined. Dietary intakes were determined by food records of 18 female sailors and energy expenditure (EE) (by doubly-labeled water) of 14, over 8 days while at sea. Reported energy intake (EI) was (mean±SD) 2302±647 kcal/d while EE was 2767±422 kcal/d; both higher than reported EI of free-living civilian women and the RDA. Relative to body weight, EI was 36±15 (range: 18–67) kcal/kg/d while EE was 44±7 (range: 33–60) kcal/kg/d, indicating physical activity was heavy. Overall body weight change (–0.6±0.9kg) was consistent with the apparent energy deficit. Mean intakes of fat and saturated fat (SFA) (38% and 13% of kcal, respectively) were significantly greater (p=.0001) than national dietary goals, such that 15 (83%) of the women got more than 10% of their EI from SFA. Only 7 (39%), 4 (22%), and 3 (17%) of the women met their individual intake goals for calcium, magnesium, and iron, respectively. Thirteen (72%) had intakes of vitamin E and folate less than the Estimated Average Requirement. Thus, interventions to promote lower-fat, nutrient-dense food choices by women on ship are indicated.

E. MARINE BASIC TRAINING FIELD STUDY

The fifth and final field study was another joint effort between Dr. DeLany at PBRC and the USARIEM. The USARIEM specific tasking by the Marine Recruiting Command was to look at attrition rates of overweight female recruits. The recruits-male and female-were allowed to come in above the screening weight, but DID MEET Marine body fat requirements. Thus, while above weight, they were not above body fat requirements. These individuals participated in all aspects of basic training-unless injured. The goal is, of course, to facilitate adequate weight reduction to meet BOTH the Marine body fat and weight standards by the time the recruit gets to the Crucible. All the recruits were weighed on schedule, and only those overweight were monitored for overweight status. The current commander of the 4th Bn (the female battalion) has made major changes in the dining facility already-the entire bn gets fat modified foods, and those on weight control get a further modified diet. (Pre-prepared low fat meals.)

STUDY DESIGN

The study spanned 12 weeks of recruit training with weekly weights and monthly measurement of body composition by dual-energy x-ray absorptiometry (or DEXA) and circumferences. The total energy expenditure of 20 subjects was measured during weeks 5 and 6 (swim week and grass week, respectively). The physical fitness test was administered prior to starting recruit training (during forming) and at week 10.

	Training Week												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Height	X												
Weight	X	X	X	X	X	X	X	X	X	X	X	X	X
DEXA	X				X				X				X
Circumferences	X				X				X				X
Total energy expenditure						X	X						
Physical fitness test	X										X		

PROGRESS

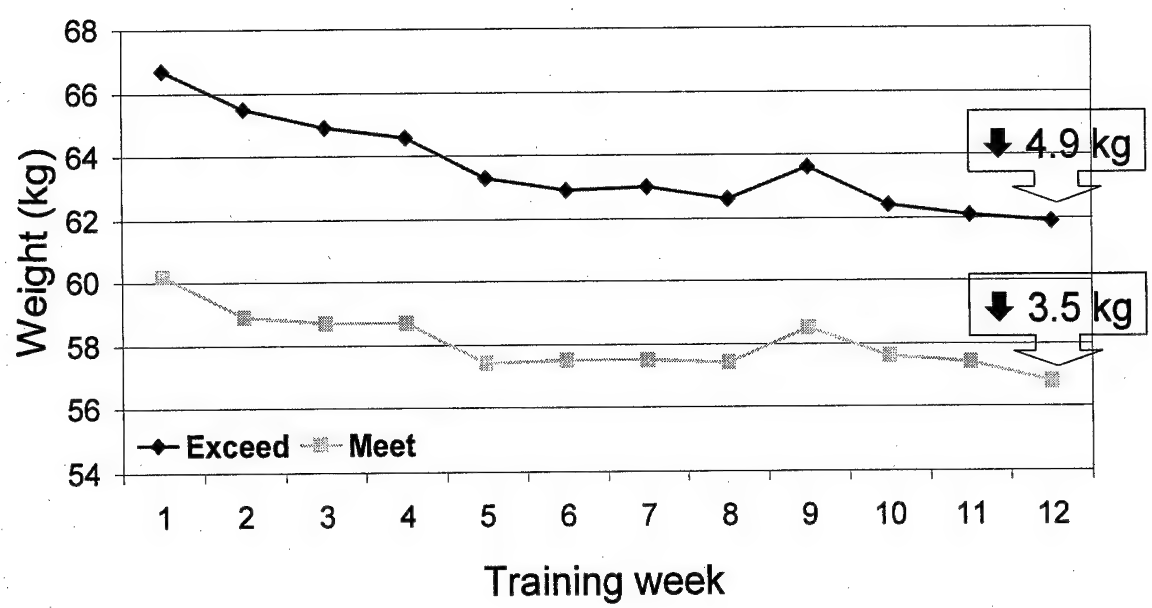
SUBJECT CHARACTERISTICS

117 recruits volunteered to participate in the research study. Over the course of recruit training, 75 completed the study. Of those studied, 29 met (MS) and 22 exceeded (ES) their USMC MAW. As expected, overweight recruits weighed more, had a higher BMI, and had a higher percent body fat (by DEXA) when compared to normal weight recruits. The overweight recruits had a significantly greater percent body fat than the 26% standard for women (P=0.0005); this was not significant in the normal weight recruits. The MS had a lower BMI than the 25

recommended by the expert panel (P=0.0005); which was NS for ES. According to national standards – these recruits would not have been considered overweight.

	Meet MAW $n = 29$	Exceed MAW $n = 22$
Age (y)	19.4 ± 1.8	20.1 ± 2.4
Height (cm)	165.5 ± 4.7	164.4 ± 5.1
Weight (kg)	60.2 ± 5.2	66.7 ± 4.7*
BMI (kg/m²)	21.9 ± 1.5	24.7 ± 1.0*
Body fat (%)	27.4 ± 5.2	33.9 ± 2.6*

Weights were taken by female Drill Instructors on Sunday morning immediately after reveille. Recruits wore minimal clothing (underwear). The weights represent what occurred during the previous week. Therefore, week 1 weight represents weight loss that occurred during the first days of recruit training while week 2 weight represents the first full week of recruit training. We did not have a final weight taken prior to graduation at week 12. As depicted below, ES lost more weight than did the MS. ES lost nearly 7% of baseline weight while MS lost 6%. Differences between the weights were significantly different at WK1 and WK12. However, the absolute weight loss was not significantly different between groups (although there was a trend towards significance with p=0.08), but this weight loss is significantly different from 0.



Associated with the weight loss was a significant loss of %BF (about 6% for MS and 7% for ES). %BF was higher in the ES compared to MS group at baseline and after recruit training (P<0.0005). Pre-post differences were significantly different within each group. However, the amount of change in %BF was not significantly different between the two groups.

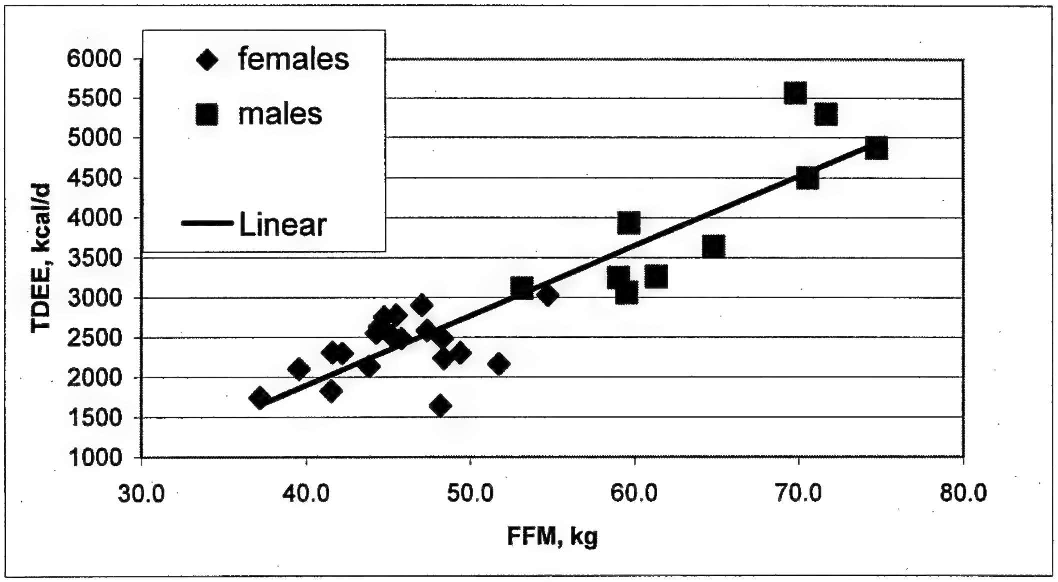
At the end of recruit training – all recruits made improvements in their physical fitness and passed the PFT. These were all significant improvements over baseline (from 0) however, one group did not improve more so than the other (FAH was approaching significance, P=0.068).

In summary, with implementation of an energy restricted diet, no recruit studied failed to graduate from recruit training because of weight gain or failure to comply with MCO 6100.10B. There was no detrimental effect of the weight loss on performance on the PFT, and in fact, we identified associations between changes in body weight and composition and improvements in physical fitness.

	Males	Females
N	10	20
Age	18.6 ± 0.8	19.7 ± 2.1
Ht, cm	173.0 ± 5.9	164.7 ± 5.4
Wt, kg	72.2 ± 8.2	61.5 ± 5.7
FFM, kg	64.5 ± 7.0	45.5 ± 4.1
TDEE, kcal/d	4048 ± 946	2378 ± 374
TDEE adjusted for FFM	2988 ± 247	2908 ± 142

The characteristics of the subjects dosed with DLW are given in the table above. The males were taller, heavier and had higher FFM than the women. Therefore, it was not surprising that the TDEE of the female recruits was considerably lower than that observed in the male recruits. After dividing TDEE by FFM (which is not the most appropriate adjustment to make) TDEE was higher in males than in females (64.5 vs 52.2 kcal/kg FFM). However, when adjusting for differences in body size appropriately, using FFM as a covariate, energy expenditure was similar in the male and female recruits (see Table above), which is particularly evident in the following graph, which plots TDEE vs FFM. The detailed stable isotope data are presented in Appendix 6.

There was no significant (p=0.123) difference in TDEE between those women who met the standard (2248±113 kcal/d) and those who exceeded the standard (2508±113 kcal/d). There was no significant difference in FFM between groups (44.8±1.3 vs 46.3±1.3 for those who met and exceeded the standard), although the mean value was higher, as was the mean TDEE. Adjusting TDEE for FFM had little effect on the TDEE results (2274±108 vs 2482±108 kcal/d for those who met and exceeded the standard; p=0.192).



F. SUMMARY OF ALL STUDIES

When all studies are combined we studied a total of 133 subjects, 80 females and 53 males. The average TDEE for all subjects (mean FFM = 54.0 ± 12.7 kg) is high, 3950 ± 1550 kcal/d. The FFM and TDEE (mean ± SD) of the men and women are presented in the Table below. FFM was significantly higher in men than women, as was TDEE. However, after adjusting for differences in FFM (FFM as a covariate in the ANOVA), there was no significant difference between genders (p=.43).

	n	FFM, kg	TDEE, kcal/d	TDEE, kcal/d Adjust for FFM
Females	80	45.9 ± 7.1	3340 ± 1270	3835 ± 80
Males	53	66.3 ± 9.0	4870 ± 1480	4125 ± 110

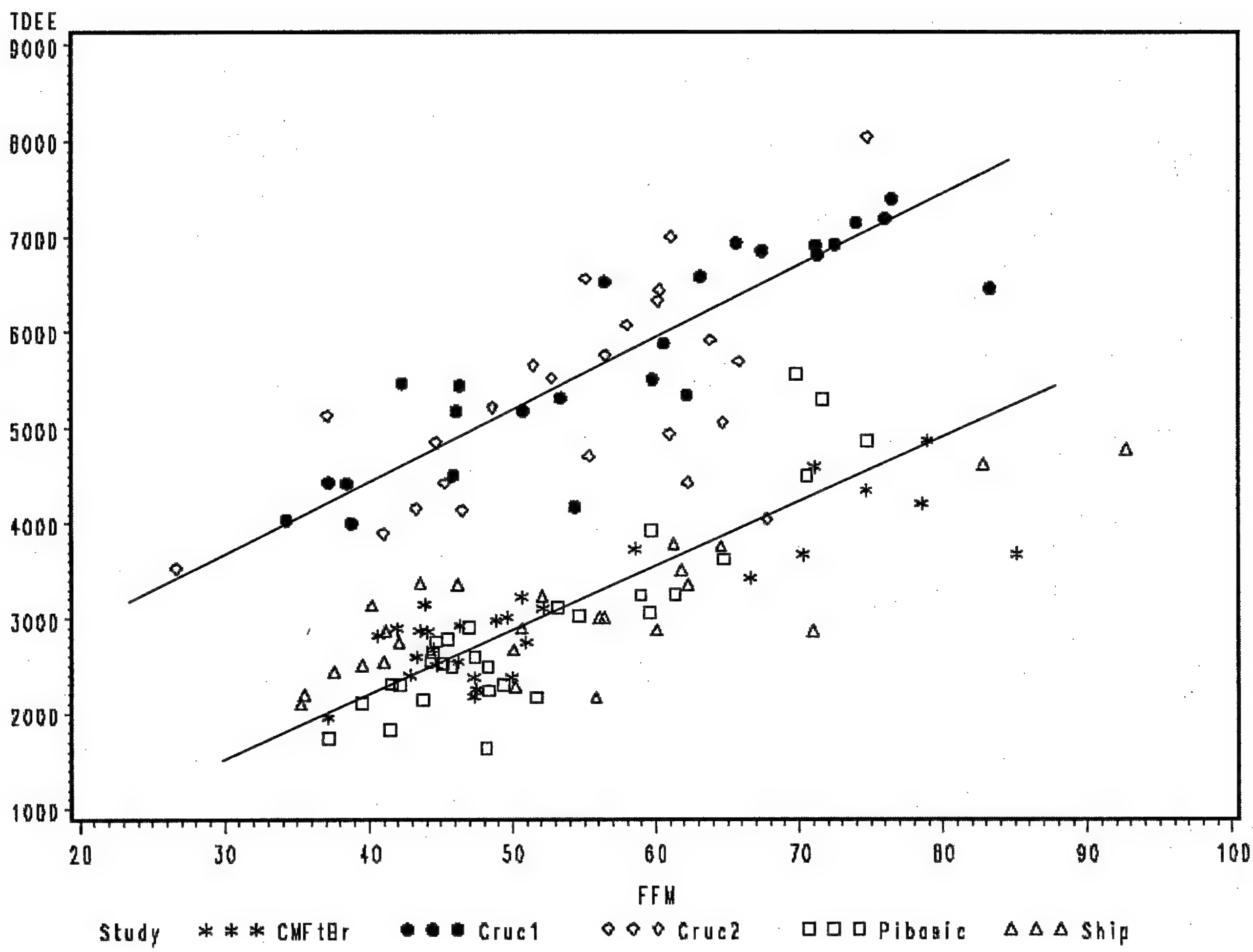
When the 5 field studies are compared, TDEE (adjusted, as in the Table below, or unadjusted for FFM) during the two crucible studies, as expected, was significantly higher than the other 3 studies. There were no significant differences in FFM between the five studies, although with some multiple means comparison adjustments FFM was higher in the first, compared to the second Crucible study, and TDEE tended to track with the FFM.

Study	**FFM, kg**	**TDEE, kcal/d**	**TDEE Significantly higher than other studies**
28 CSH	58.1 ± 1.6	3035 ± 116	
Crucible 1	57.6 ± 1.6	5540 ± 115	***
Crucible 2	54.4 ± 1.6	5290 ± 115	***
Marine Basic	55.0 ± 1.5	3150 ± 110	
Shipboard	56.3 ± 1.6	2990 ± 120	

A summary of TDEE for female and male subjects for all 5 studies is presented the Table below. In each study, unadjusted TDEE was higher in males compared to females, due to the males being larger than females. After adjustment of TDEE for body size using FFM as a covariate, TDEE was similar in male and female soldiers in every field study.

	TDEE, kcal/d (unadjusted)		Gender Difference in TDEE	
Study	**Females**	**Males**	**Unadjusted**	**Adjusted**
28 CSH	2700 ± 170	3880 ± 250	Yes	No
Crucible 1	5150 ± 1.6	6380 ± 210	Yes	No
Crucible 2	4900 ± 220	5725 ± 220	Yes	No
Marine Basic	2380 ± 170	4050 ± 240	Yes	No
Shipboard	2810 ± 190	3470 ± 250	Yes	No

The following graph summarizes the data from the 5 field studies. It is quite apparent that there are two distinct lines of TDEE vs. FFM, the upper line which is the two Crucible Studies, and the bottom line which includes the other 3 studies. In addition, it is also clear that the subjects with the lower FFM (mainly the women) and the higher FFM (mainly the men) all fall along the same line.



6. Key Research Accomplishments

- Completed Combat Support Hospital Field Training Exercise. This was a fairly low level energy expenditure study showing that men and women undergoing the same FTX show similar energy expenditure when adjusting for differences in body size
- Completed 2 studies in Marine Recruits undergoing the very intense Crucible event. We observed very high energy expenditures in the men and women. Based on activity monitoring, the men and women underwent similar intensity training. When adjusting for differences in body size, the men and women expended similar activities.
- The Shipboard study was completed.
- The Marine Basic Training study was completed at Parris Island. This study included both overweight and normal weight women, and men undergoing basic training.
- The foot contact monitor was validated in the lab, and in the field compared to TDEE by DLW.

7. Reportable Outcomes

Castellani, J.W., R.W. Hoyt, A.J. Young, J. DeLany, J. Gonzalez, C. O'Brien, J. Moulton, and W.R. Santee. Core temperature and energy expenditure during the Crucible Exercise at Marine Corps Recruit Depot, Parris Island. *USARIEM Technical Report* 98-26, 1998.

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Tharion, W.J., J.P. DeLany, and C.J. Baker-Fulco. Total daily energy expenditure of male and female soldiers during a field training exercise. *FASEB J* 15:A988, 2001.

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Tharion, W.J., M. Yokota, M.J. Buller, J.P. DeLany, and R.W. Hoyt. Prediction of shipboard total daily energy expenditures (TDEEs) using pedometry. *FASEB J* 16 (5):A859.38, 2002.

8. CONLUSIONS

Overall the field studies went very smoothly. As originally planned, 5 field studies were conducted. A total of 80 Females (FFM = 45.9 ± 7.1 kg) were studied with an average of total daily energy expenditure of 3340 ± 1270 kcal/d. A total of 53 males (66.3 ± 9.0 kg FFM) were studied, with an average total daily energy expenditure of 4870 ± 1480 kcal/d. Since the men were larger than women in all studies, the men had a higher total daily energy expenditure than women overall, and in each individual study. However, when adjusting for differences in body size, the energy expenditure of men and women were similar in all studies. Energy expenditures during the short term Crucible studies were very high, possibly some of the highest energy expenditures we observed, and higher than the other 3 studies. The Crucible studies provided an excellent paradigm to examine energy expenditures between men and women because all recruits underwent essentially the same activities and were on the same sleep/wake regimen.

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10. Appendices

Appendix 1. Body weight changes and dietary intake for January Crucible Study

January 98 Men, g 101 123 448

		Weight					Women, g	92	105	324
Subj#	Age	Initial	Final	Loss	subj#	Total		PRO	FAT	CHO
1	19	73.2	68.5	4.7	1	5387	3343	544	1595	3388
2	19	65.2	63.0	2.2	2	1980		221	840	945
3	19	64.4	62.3	2.1	3	2084		206	941	1255
4	19	86.0	84.0	2.0	4	2824		447	964	1585
5	18	81.3	77.5	3.8	5	2628		361	1093	1196
6	22	88.1	84.6	3.5	6	2107		398	856	880
7	19	61.4	57.9	3.5	7	3152		590	1253	1354
8	19	84.2	79.7	4.5	8	3218		318	1241	1748
9	25	76.2	74.6	1.6	9	3350		372	1135	1888
10	18	67.3	64.6	2.7	10	4580		430	1431	2778
11	26	80.9	76.8	4.1	11	3293		363	1019	1946
12	19	72.0	68.9	3.1	12	5516		504	1367	3811
13	18	66.4	63.2	3.2	16	2149	2592	336	588	1273
14	19	81.2	76.6	4.6	17	1988		269	968	791
15	19	73.2	70.2	3.0	18	3048		303	1244	1577
16	19	53.4	51.5	1.9	19	3167		312	1040	1832
17	18	63.4	62.2	1.2	21	2403		440	1040	960
18	18	62.1	60.5	1.6	23	2200		340	736	1169
19	20	68.5	67.4	1.1	25	3187		330	979	1809
20	19	46.7	45.6	1.1						
21	19	66.1	64.4	1.7						
22	18	72.9	70.8	2.1						
23	20	44.9	43.4	1.5						
24	19	44.7	42.8	1.9						
25	21	58.7	57.1	1.6						

	PRO	FAT	CHO
Men	396	1145	1898
	99	127	474
Women	333	942	1344
	83	105	336

Appendix 2. Body weight changes and dietary intake for February Crucible Study

February 98

		Weight								
	Age	Initial	Final	Loss	subj#	Total		PRO	FAT	CHO
1	21	72.2	68.0	4.2	1	2995	3135	337	1041	1648
2	19	70.9	67.4	3.5	2	2951		371	1118	1517
3	19	80.0	76.2	3.8	3	3466		425	1122	1929
4	21	80.7	77.5	3.2	4	3919		380	1232	2347
5	20	87.0	84.3	2.7	5	4068		472	1183	2509
6	19	72.7	69.9	2.8	6	3485		602	1333	1603
7	18	67.9	65.6	2.3	7	3443		418	1256	1820
8	21	70.4	67.6	2.8	8	1995		367	619	1008
9	18	85.7	82.6	3.1	9	3195		443	1187	1595
10	19	75.7	73.3	2.4	10	3943		549	1133	2268
11	19	68.2	65.3	2.9	11	1472		131	624	770
12	20	69.1	66.4	2.7	12	2056		436	941	693
13	24	60.8	57.5	3.3	13	3695		459	1238	2007
14	22	65.7	62.9	2.8	14	4716		550	1581	2669
15	22	66.6	63.7	2.9	15	1629		202	535	902
16	19	65.9	64.7	1.2	16	2392	2568	417	700	1282
17	19	65.6	62.6	3.0	17	5227		881	1927	2489
18	18	61.6	60.0	1.6	18	1218		137	483	623
19	23	53.5	51.5	2.0	19	2933		507	1260	1224
20	28	65.5	65.0	0.5	20	2218		441	922	894
21	19	62.2	60.3	1.9	21	1939		249	699	1019
22	23	46.5	44.7	1.8	22	3831		510	1325	2020
23	18	53.6	51.8	1.8	23	2616		441	1049	1175
24	20	59.5	58.5	1.0	24	2022		283	695	1079
25	18	56.9	54.7	2.2	25	1284		160	475	673

	PRO	FAT	CHO
Men	409	1076	1686
	102	120	421
Women	403	954	1248
	101	106	312

Appendix 3. Energy expenditure for First Crucible Study.

Energy Expenditure (EE): Parris Island 1/98 Crucible Study

S#	TBW	KO	KD	EE kcal/d			Body Wt.	kcal/kg		
#1	48.07	0.21465	0.16702	**6937**	**Men**		70.1	99.0		
#2	41.35	0.20148	0.15044	**6532**	**Mean**	**SD**	69.2	94.5		
#3	45.54	0.16409	0.12567	**5350**	**6448**	**868**	78.1	68.5	**91.1**	**15**
#4	52.21	0.16848	0.12623	**6817**			79.1	86.2		
#5	55.99	0.26230	0.21650	**7407**			85.7	86.5		
#6	60.98	0.15041	0.11566	**6464**			71.3	90.7		
#7	39.81	0.12498	0.09135	**4180**			66.8	62.6		
#8	54.18	0.16463	0.12208	**7154**			69.0	103.7		
#9	49.38	0.17743	0.13257	**6854**			84.2	81.5		
#10	43.79	0.14605	0.10587	**5510**			74.5	74.0		
#11	55.67	0.14574	0.10458	**7199**			66.8	107.9		
#12	44.37	0.13718	0.09535	**5888**			67.8	86.9		
#13	46.24	0.12346	0.07934	**6585**			59.2	111.3		
#14	53.10	0.16296	0.12094	**6923**	**Women**		64.3	107.7		
#15	52.12	0.16778	0.12497	**6912**	**Mean**	**SD**	65.2	106.1		
#16	30.99	0.15145	0.09686	**5467**	**4800**	**576**	65.3	83.7	**83.5**	**15**
#17	33.61	0.19337	0.14931	**4507**			64.1	70.3		
#18	33.93	0.20279	0.15102	**5444**			60.8	89.5		
#19	25.10	0.57418	0.51009	**4042**			52.5	77.0		
#20	28.41	0.15200	0.10736	**4006**			65.3	61.4		
#21	37.17	0.14950	0.10536	**5185**			61.3	84.7		
#22	39.09	0.11135	0.06944	**5316**			45.6	116.6		
#23	27.26	0.17041	0.11909	**4433**			52.7	84.1		
#24	28.17	0.15705	0.10773	**4423**			59.0	75.0		
#25	33.77	0.15591	0.10765	**5179**			55.8	92.8		

Average TBW estimated as ½ average body weight loss - body stores used for energy.

Appendix 4. Energy expenditure for Second Crucible Study.

Energy Expenditure: Parris Island 2/98 Crucible Study,

S#	TBW	KO	KD	EE kcal/d	Body Wt	kcal/kg
#1	44.74	0.19029	0.14003	**7001**	70.9	98.8
#2	44.07	0.15318	0.10774	**6331**	64.1	98.8
#3	46.73	0.21904	0.17623	**5920**	63.4	93.4
#4	48.18	0.15348	0.11519	**5695**	85.0	67.0
#5	54.75	0.16711	0.12028	**8048**	79.4	101.4
#6	42.45	0.15360	0.10829	**6076**	86.4	70.4
#7	44.14	0.24906	0.19983	**6446**	59.7	108.1
#8	39.09	0.24314	0.21121		82.0	
#9	49.66	0.12981	0.10262	**4050**	75.4	53.7
#10	47.38	0.22328	0.18594	**5058**	66.0	76.7
#11	45.59	0.12737	0.09585	**4431**	78.9	56.2
#12	44.64	0.13038	0.09497	**4942**	70.5	70.1
#13	40.53	0.09639	0.06055	**4709**	64.8	72.7
#14	41.36	0.15649	0.11223	**5753**	78.9	72.9
#15	40.38	0.17042	0.11912	**6562**	71.7	91.5
#16	38.64	0.14845	0.10336	**5524**	52.5	105.3
#17	37.71	0.20600	0.15706	**5656**	62.8	90.1
#18	33.15	0.14191	0.09969	**4426**	61.3	72.2
#19	19.51	0.65661	0.58424	**3530**	68.0	51.9
#20	35.61	0.20896	0.16092	**5214**	46.2	113.0
#21	32.71	0.17785	0.13030	**4850**	65.3	74.3
#22	27.16	0.21229	0.15222	**5127**	71.9	71.4
#23	30.05	0.12875	0.08804	**3897**	44.2	88.3
#24	34.08	0.17554	0.13562	**4139**	43.8	94.6
#25	31.72	0.13451	0.09317	**4164**	57.9	71.9

Men	
Mean	**SD**
5787	**1085**

80.8	**18**

Women	
Mean	**SD**
4653	**725**

83.3	**18**

Appendix 5. Stable Isotope Data For Shipboard study.

Subject Number	Total Body Water (kg) O^{18}	Total Body Water (kg) Deuterium	Fat Free Mass (kg) O^{18}	Fat Free Mass (kg) Deuterium	Energy Expenditure (kcal/d) 2 Point Method	Energy Expenditure (kcal/d) Regression Method
Females:						
#101	26.0	26.5	35.5	36.1	2035	2191
#103	25.8	26.1	35.3	35.6	2094	2103
#104	31.9	33.0	43.6	45.1	3310	3372
#105	37.1	37.9	50.7	51.8	3260	2902
#106	30.0	30.5	41.0	41.6	2531	2544
#107	36.6	37.4	50.1	51.1	2427	2676
#108	30.8	31.6	42.1	43.2	2709	2757
#109	33.8	34.3	46.2	46.9	3160	3359
#110	36.8	37.6	50.2	51.4	2317	2281
#111	38.1	38.9	52.1	53.2	3083	3237
#112	30.2	31.0	41.2	42.3	2792	2879
#119	28.9	28.2	39.5	38.6	2403	2508
#120	41.1	40.6	56.1	55.5	2938	3018
#123	29.4	30.0	40.2	41.0	3314	3141
#128	27.5	26.4	37.6	36.1	2287	2443
#113	45.3	43.2	61.8	59.0	3237	3518
Average	33.1	33.3	45.2	45.5	2743.5	2808.1
St Dev.	5.4	5.2	7.4	7.2	437.5	429.2
Males:						
#114	47.3	46.7	64.6	63.7	3617	3769
#116	67.8	66.6	92.7	90.9	4811	4781
#117	41.3	41.3	56.4	56.4	2967	3012
#129	60.6	59.5	82.8	81.3	4536	4623
#131	44.8	47.2	61.3	64.5	3656	3789
#133	44.0	45.7	60.1	62.4	3052	2881
#134	45.6	46.4	62.3	63.4	3351	3358
#135	51.9	52.4	71.0	71.6	2655	2875
#136	40.9	41.6	55.9	56.8	2125	2168
Average	49.4	49.7	67.4	67.9	3418.9	3472.9
St. Dev.	8.7	7.9	11.9	10.8	808.5	806.6

Appendix 6. Stable Isotope Data For Marine Basic Training study.

S#		TBW	TBW	KO	KD	EE	FFM	TDEE,kcal/d	
		O18	HD			Kcal/d	(18O)	Mean	SD
1	F	29.0	29.5	0.1434	0.1168	2107	39.5	2378	374
2	F	36.1	36.9	0.2202	0.1939	2306	49.4		
3	F	30.9	31.5	0.1979	0.1691	2301	42.2		
4	F	34.7	35.3	0.1638	0.1360	2590	47.4		
5	F	34.4	35.2	0.2141	0.1818	2910	47.0		
6	F	32.4	35.0	0.1846	0.1549	2556	44.3		
7	F	32.7	35.2	0.1808	0.1496	2760	44.7		
8	F	30.4	31.4	0.1621	0.1341	2310	41.6		
9	F	37.9	39.4	0.1489	0.1268	2168	51.7		
10	F	27.2	28.7	0.2248	0.1982	1748	37.2		
11	F	32.1	32.7	0.1739	0.1482	2139	43.8		
12	F	33.3	35.7	0.1461	0.1163	2783	45.5		
13	F	35.3	35.5	0.2383	0.2165	1645	48.2		
14	F	40.1	41.2	0.1692	0.1409	3033	54.7		
15	F	30.4	31.3	0.1555	0.1323	1831	41.5		
16	F	33.1	34.3	0.1385	0.1111	2524	45.2		
17	F	35.4	35.6	0.1428	0.1192	2239	48.4		
18	F	35.4	37.2	0.1630	0.1365	2489	48.3		
19	F	32.5	33.2	0.1461	0.1170	2637	44.5		
20	F	33.5	33.8	0.1691	0.1413	2489	45.8	Males	
21	M	38.9	40.0	0.1422	0.1135	3114	53.2	4048	946
22	M	43.2	44.0	0.1594	0.1316	3248	59.0		
23	M	43.6	44.0	0.1760	0.1492	3062	59.6		
24	M	52.5	54.7	0.2058	0.1688	5299	71.7		
25	M	51.1	55.5	0.1801	0.1416	5567	69.8		
26	M	43.7	44.6	0.1547	0.1226	3930	59.7		
27	M	51.7	54.7	0.1385	0.1078	4501	70.6		
28	M	54.7	55.9	0.1513	0.1196	4873	74.8		
29	M	44.9	46.2	0.1286	0.1027	3259	61.4		
30	M	47.5	47.6	0.1386	0.1111	3630	64.8		